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AUTOMATIC DUST SAMPLING AND ANALYZING INSTRUMENTS FOR ATMOSPHERIC POLLUTION SURVEYS

By W. F. DAVIDSON and WARREN MASTER
[Consolidated Edison Co. of New York, Inc., October 1941]

INTRODUCTION

A few years ago, Consolidated Edison Co. of New York began a survey of atmospheric pollution. The Weather Bureau is now cooperating in this survey; and it is considered that a description of the instruments used in this research will be helpful to everyone interested in the program. These instruments have been developed during the course of the survey and they have been found entirely satisfactory.

None of the available recording instruments used in previous surveys of this nature was entirely satisfactory. It was deemed desirable, however, to retain the advantage of a basis of comparison with earlier studies. This was done by improving the Owens automatic air filter; during the development, the serious defects of this instrument were eliminated, but its essential features were retained so that present records are comparable with previous records.

The automatic air filter, developed by J. S. Owens for the British atmospheric pollution survey, consists of a time-controlled water syphon which periodically draws 2,000 cubic centimeters of air through an orifice pressing on the periphery of a filter paper disk. The diameter of the orifice is one-eighth of an inch. The dust concentration is determined by measuring the degree of the darkening on the filter papers, and applying a conversion factor to express the results in "tons per cubic mile" or corresponding other units.

The most serious objection to the Owens recorder was the use of water. In winter it was necessary to operate this instrument inside where water supply was available. Inside operation required an objectionably long sampling tube. A less serious difficulty in the Owens recorder was the use of a circular chart requiring daily change. Records of these earlier surveys were subject to inaccurate evaluation because of the lack of a device for measuring the degree of darkening, or shade number, on the filter paper.

IMPROVED AUTOMATIC SAMPLER

Since 60-cycle alternating current services with regulated frequency are generally available at all locations where the samplers may be installed, it was decided to make the new instrument electrically operated. A motor-driven exhaust pump and a diaphragm gas meter for measuring the air volume were substituted for the water syphon of the Owens recorder. A small synchronous motor of the telechron type was used for time control and the disk record of the older instruments was replaced by a strip chart. A minor change, made in the interests of facilitating the measurement of the degree of darkening, consisted in enlargement of the dust-spot area from ⅛-inch diameter to 5/16-inch diameter. The instrument, as finally developed, is shown photographically in figure 1 and schematically in figure 2.

The arrangement and method of operation of the instrument is readily apparent from figure 2. Timing and the movement of the record tape are controlled by the small synchronous motor (1) operating through reduction gearing to drive a shaft at 1 revolution per hour. Mounted on this shaft is a cam (2) which moves switch (17) alternately from one position to the other each half hour, thus completing the circuits necessary to start the train of sampling operations. A Geneva gear intermittent motion (3) operates the feed drum (5) and the take-up reel (7) in such way as to advance the record tape three-fourths of an inch between sampling periods. When switch (17) moves

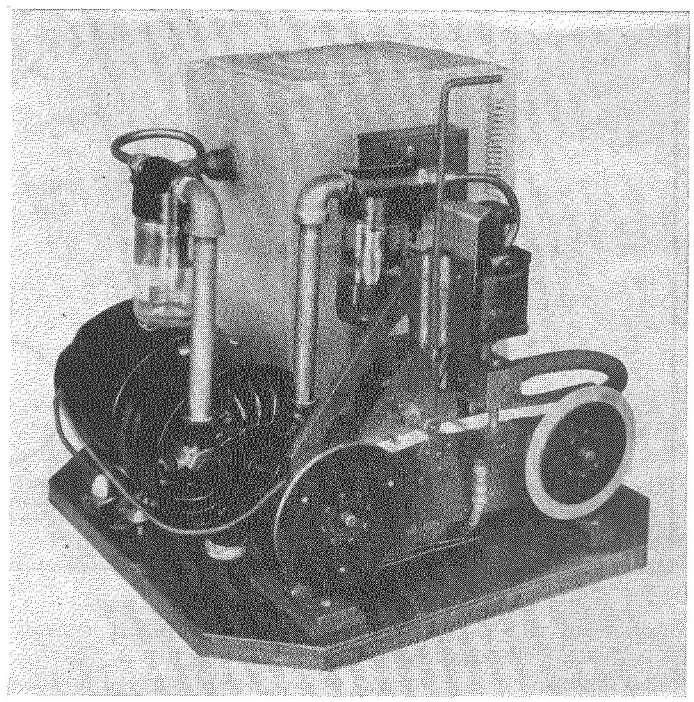

FIGURE 1.—Automatic strip-chart dust sampling machine with cover removed.

to "start" position (as indicated) circuits will close, energizing the solenoid magnet (10) which forces the clamping blocks (9) on to the record tape. At the same time, the motor (12) driving the exhaust blower will start. This will draw a sample of air from intake (8), through the filter paper record tape and will discharge it to atmosphere through the meter (14) where the quantity is measured. When 1 cubic foot of air has passed through the meter, the cam (15) will move switch (16) to the opposite position, opening the circuits, thus stopping the exhauster and allowing the clamping blocks to separate, freeing the record tape. The size of the exhauster is such that the sampling operation requires about 6 minutes.

The decision to use strip record tapes instead of disks made it necessary to solve several problems. The tapes were to be 16 mm. wide and about 60 feet long, enough for 20 days' operation. The filter paper selected is similar to that used by Owens. It is of superior grade white stock with a porosity of 12 to 15 seconds per 100 cc. of air as measured by the Gurley densometer. The reflection coefficient (white light) is 0.84 as determined by Hardy recording spectrophotometers. It was necessary to develop an accurate indexing of the dust spot for the photometer which was to be used for determining the degree of darkening. The use of a perforated tape for indexing purposes was impractical because of shrinkage and expansion with changes in moisture content. The problem was solved by incorporating a punch in the clamping blocks (9). Two punch pins were mounted in the upper block on opposite sides of the 5/16-inch (7.94 mm.) diameter orifice, and corresponding holes were drilled in the lower block. These punches thus index an unperforated tape. The indexing holes are accurately punched in the tape on each side and directly opposite the center of the dust spot as shown in figure 3.

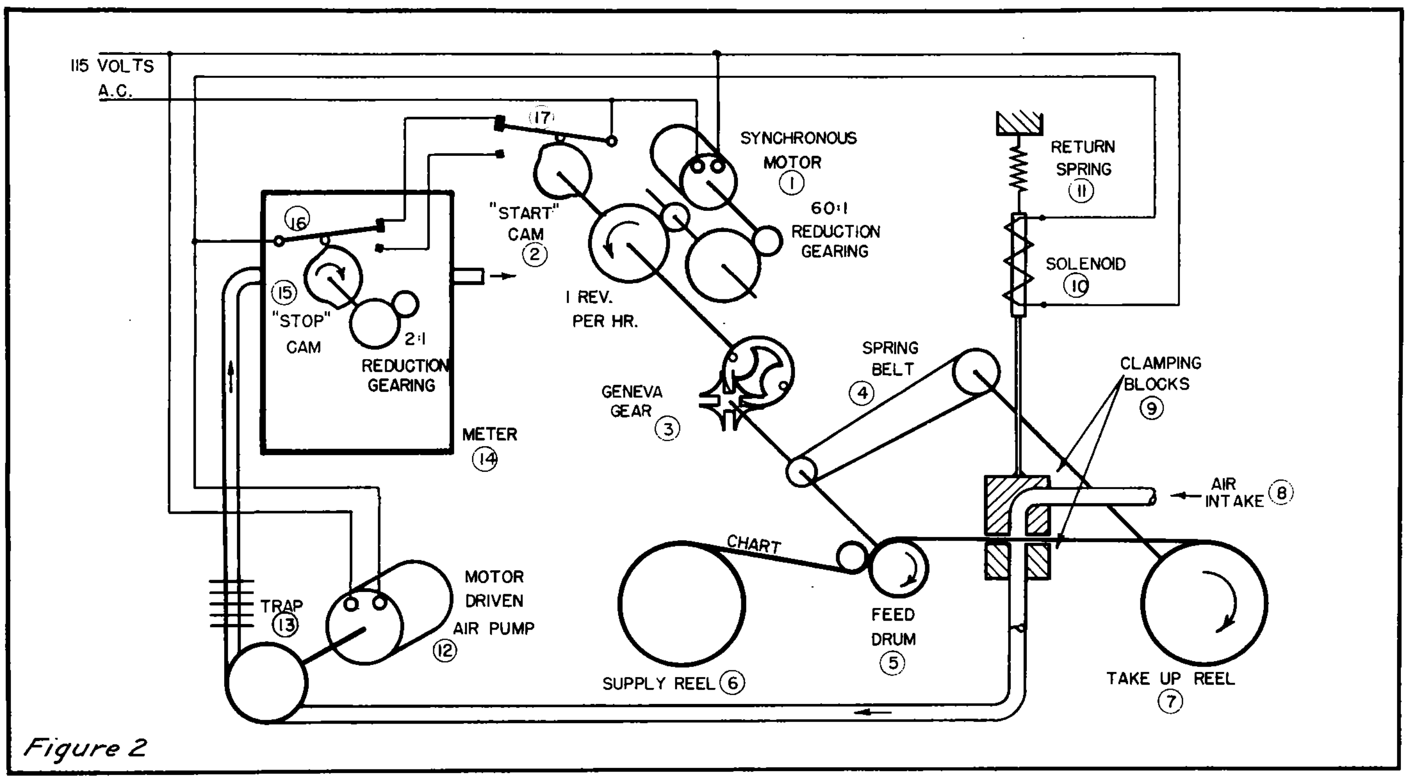

FIGURE 2.

The sampler is mounted on a convenient pipe frame stand as shown in figure 4. It is protected by a metal cover which also serves to hold a deposit gage. The inlet tube extends a few inches below the instrument base.

The principal component parts were purchased from regular commercial sources.

CHART-EDITING MACHINE

The use of plain strip material for charts made it necessary to edit the individual records after they were removed from the sampler in order to determine the time of the records. The only previous notations on the record were the time of the first and the last dust spots. To facilitate the time determination, the chart editing machine, shown in figure 5 was constructed. This machine was constructed so that a small pin can move into the perforations on the side of the tape made by the punch. The movement of the pin operates an electrical counter circuit or gives an audible indication of the time.

PHOTOELECTRIC SCANNING MACHINE

The use of a semiautomatic photoelectric scanner for determining the "shade number," or degree of darkness of the dust spots on the record tape, was considered essential for the investigation. The method of making a visual match with a standard scale of grays, as used by Owens, was not only slow and laborious but open to serious error unless trained observers were used. Even with trained observers the statistical sampling variance would, *a priori*, be quite large as compared with a more rigorous and specific scientific technique. The ratio of the pollution of an actual sample to the pollution of the fixed sample will not exceed 2 to 1; therefore the range in brightness of the spots is not great. Such small range would require the matching of brightness to 5 percent in order to read 1 unit on a scale of 10. Such accurate matching is beyond the ability of random observers unless the lighting and other conditions of observation are carefully controlled.

The photoelectric scanning machine is shown photographically in figure 6 and schematically in figure 7. The photometric system consists of a tungsten filament lamp (20) operated at fixed voltage from a constant voltage transformer (19) with the filament focussed, by a single lens (21), to a spot about 7 mm. diameter on the record tape. Reflected light from the spot is picked up by a barrier-type self-generating cell (22). Since it was desirable to have a pointer-type indicating instrument (23) connected so that it would read zero for the unsoiled tape and show increased deflections as the spots became darker, a compensating circuit was provided to neutralize the voltage from the cell when the unsoiled tape was in position. In operation, a section of unsoiled tape is placed in the measuring position and adjustment (24) is used to bring the meter to zero reading. A standard gray chart of known shade number is then introduced and the sensitivity adjustment (25) is used to bring the pointer

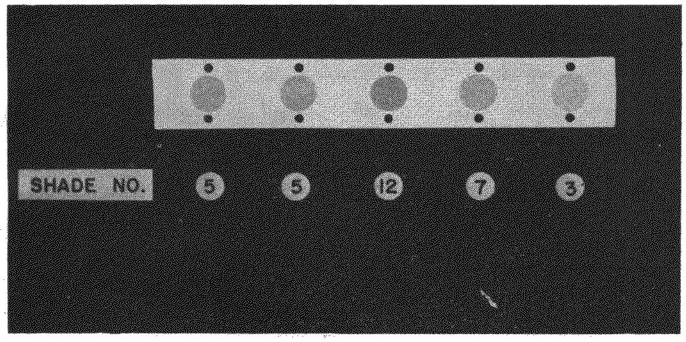

FIGURE 3.—Section of typical dust chart showing punched holes and shades of gray obtained with partial range of dust concentrations encountered.

to the proper deflection. If necessary, the adjustments are repeated for more certain check.

The chart is moved forward from position to position by an automatic mechanism under the control of the

FIGURE 4.—Dust sampling station on roof of a 20-story New York building. Funnel-shaped device on cover measures fall of large-size dust particles.

operator. To move the chart the operator presses "start" button (32), thus energizing solenoid (34) and causing it to withdraw the pin (31) from the indexing hole in the tape. At the same time, contacts (35) are closed (the switch (37) having been closed to make the machine operative) and this starts motor (33) which advances the tape. In the meantime the operator has released push button (32) deenergizing the solenoid, but the switch (35) is kept closed by the pressure of the tape on the pin. When an indexing hole comes into position, pin (31) rises, opening contacts (35) and stopping the feed motor. The presence of the pin in the tape holes and elasticity of the tape between that point and the feed drum insure the accurate position of the dust spot under the focussed light spot. The small contactor (38) is provided merely to give added damping to the meter and prevent violent needle swings between spots.

In determining the scale of shade numbers, black was arbitrarily assigned a value of 50; but as a matter of con-

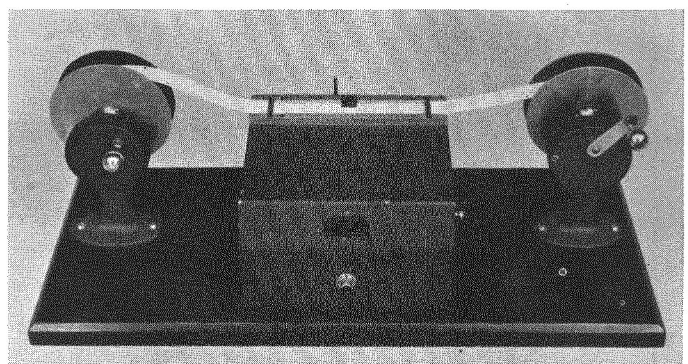

FIGURE 5.—Chart-editing machine for inspecting, marking, and splicing charts for scanning machine.

venience and to get a better instrument scale, the scale was divided into 20 units. A calibrated gray card is used for making adjustments as previously described. The gray for shade No. 20 has a reflection factor for white

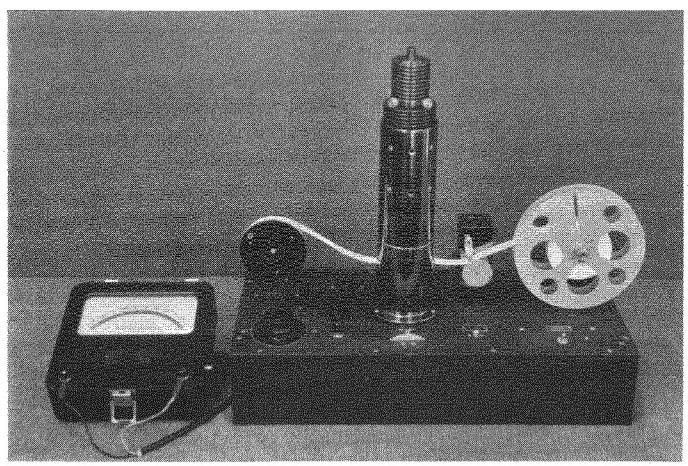

FIGURE 6.—Photoelectric scanning machine. Note special shade number scale on microammeter.

light of 0.48, as measured by the Hardy photometer, with nearly uniform values throughout the visible spectrum (i. e., it is a true gray). This method of shade determination has a distinct advantage over visual matching with a standard chart. Since the instrument is adjusted to read zero on the unsoiled chart, no discoloration of the tape due to age will affect the shade-number readings. This important advantage is apparent. On some unused Owens charts, after several years of storage, background readings corresponding to shade 2 were obtained when no initial correction was applied.

Readings to better than one-half shade number on the scale of twenty are obtained; but for survey purposes, readings are reported to the nearest whole number.

The principal component parts of this instrument also were purchased from regular commercial sources.

It is planned to present in another paper the results obtained with this instrument in an atmospheric-pollution survey of the New York City metropolitan area.

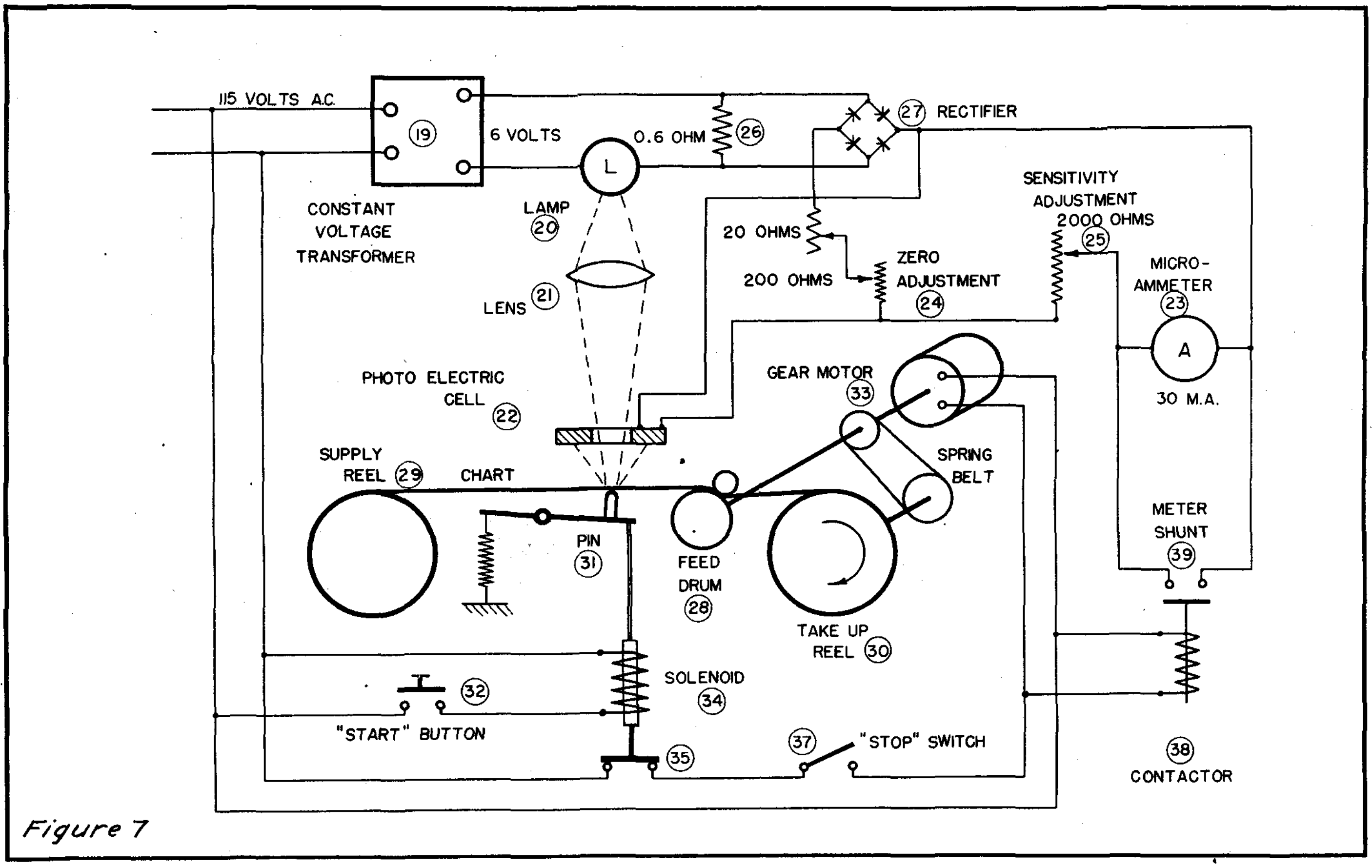

FIGURE 7.

THE GEOMETRICAL THEORY OF HALOS—VI [1]

By EDGAR W. WOOLARD

[Weather Bureau, Washington, D. C., September 1941]

PART 3. THE OPTICAL METEORS PRODUCED BY ICE CRYSTALS IN THE ATMOSPHERE

Among the innumerable crystalline forms produced by the condensation of water vapor in the atmosphere at temperatures below freezing, as illustrated, e. g., in frostwork and by snowflakes, there are two or three quite simple ones from which all the others may be built up, viz, hexagonal columns with or without pyramidal caps (complete or truncated) and hexagonal plates; the columns are sometimes capped with plates, and the pyramids may occur unattached to columns.

These elementary forms (figure 19) are frequently observed in snow and frost at low temperatures, especially in polar regions; they often are present in the atmosphere at the surface of the earth when a halo display is witnessed, and there is every reason to believe that it is some one or more of them, or simple combinations thereof, which ordinarily produce halos, and not the complicated crystal groups and patterns shown in general by snowflakes—in fact, the majority of authenticated halos do not require anything more complicated than a simple hexagonal right prism (column or plate).

The present investigation will therefore be restricted to hexagonal right prisms (in the form of either columns or disks), hexagonal right pyramids (complete or truncated), and simple combinations of these two forms.

From the six lateral faces and two bases of a hexagonal right prism, taken two at a time, may be formed 28 possible combinations. Of these combinations, one consists merely of the two bases, which form a refracting angle of 0° and do not produce any resultant deviation; 15 are combinations between lateral faces, of which 3 are between opposite faces and again form 0° angles, and 6 are between adjacent faces and form angles of 120° through which no transmission is possible; 6 are between alternate faces, and all form truncated 60° refracting angles; 12 are combinations of a lateral face with a base, forming in all cases a refracting angle of 90°.

To determine all the halos which a hexagonal right prism with plane bases is capable of producing, it is necessary to calculate, for each of all orientations of the prism in space, the images obtained by refraction through the six 60° angles between alternate lateral faces and through the twelve 90° angles between lateral faces and bases, together with the images formed by reflection (external, and internal with or without accompanying refraction) from the six lateral faces and two bases. The refracting edges of the 60° angles are parallel to the principal axis of the crystal, and those of the 90° angles are perpendicular to the principal crystal axis.

In pyramidal crystals, the triangular faces may, according to the laws of crystallography, have any one of several different inclinations to the principal axis of the crystal, these different values being connected by simple numerical relations. Unfortunately, the possible inclinations can be

[1] The previous papers have appeared in the MONTHLY WEATHER REVIEW as follows: I, 64:321-325, 1936; II, 65:4-8; III, 65:55-57; IV, 65:190-192; V, 65:301-302, 1937. The figures in the present paper are numbered consecutively with those in the earlier papers.